NTSB National Transportation Safety Board

Engineering Design: Insights into Highway Bridge and Tunnel Disasters

INCOSE – Chesapeake Chapter
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Laurel, MD

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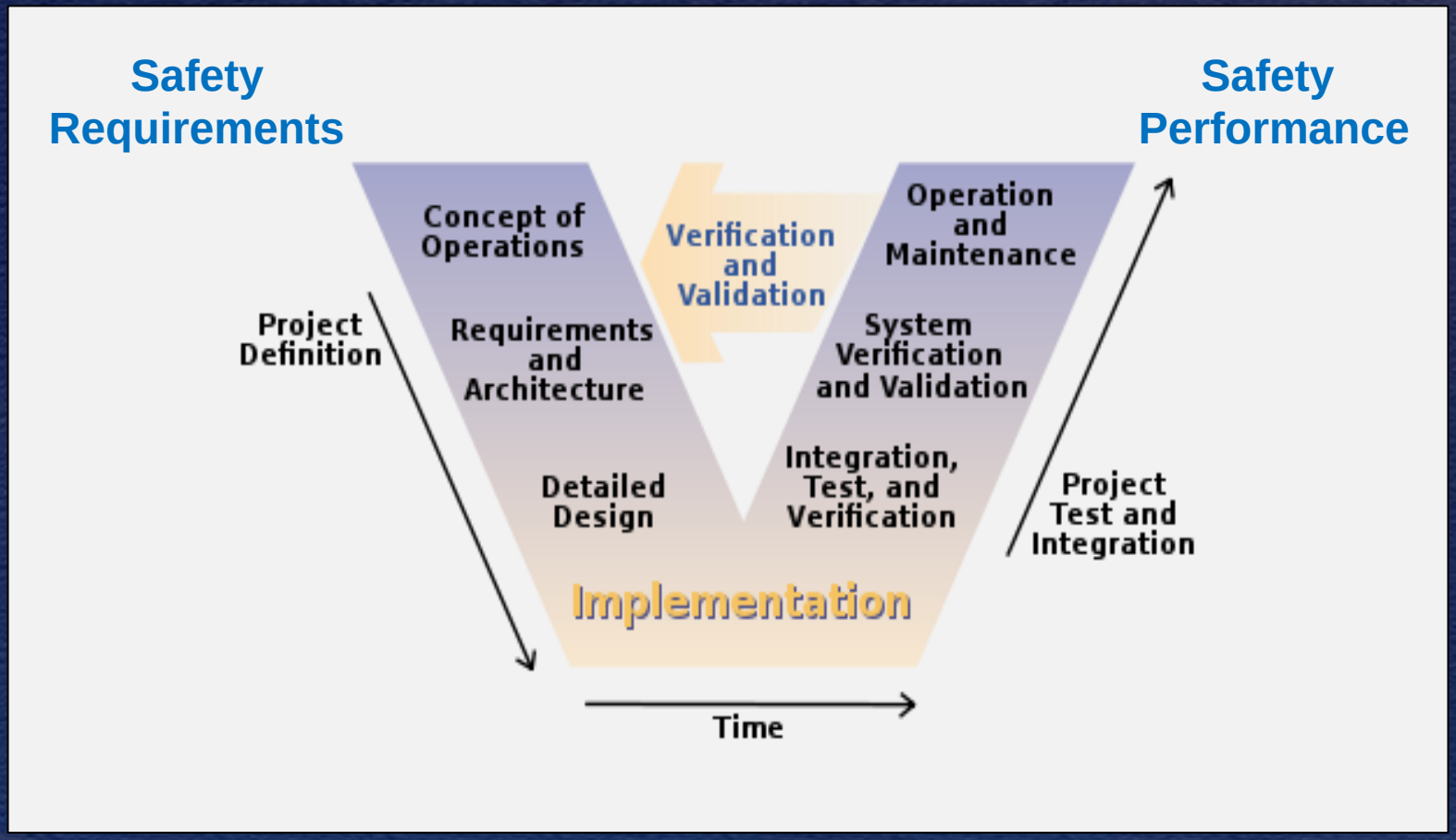
Member, NTSB

NTSB Mission

The NTSB is an independent US federal agency charged with determining the probable cause(s) of transportation accidents, making recommendations to prevent their recurrence, conducting special studies and investigations, and coordinating resources to assist victims and their families after an accident.

Generalized System Engineering V



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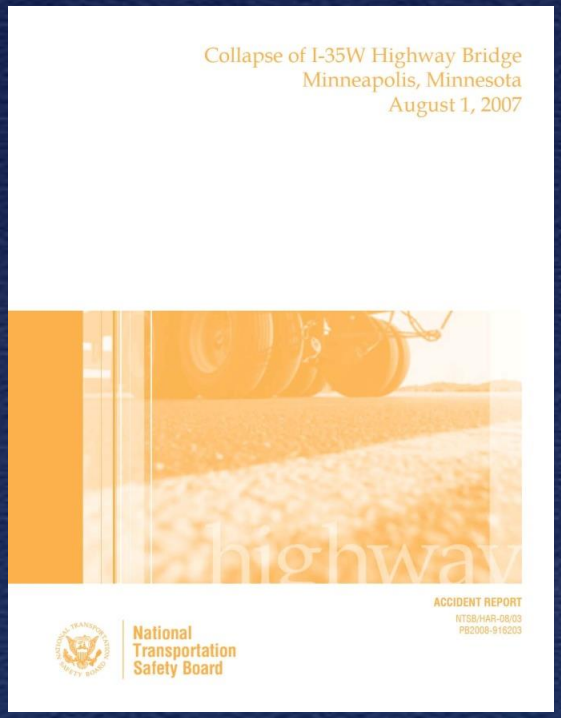
Collapse of I-35 Highway Bridge Minneapolis, MN




I-35W Bridge
Downtown District
Source: Google Earth

Video Sequence of bridge collapse

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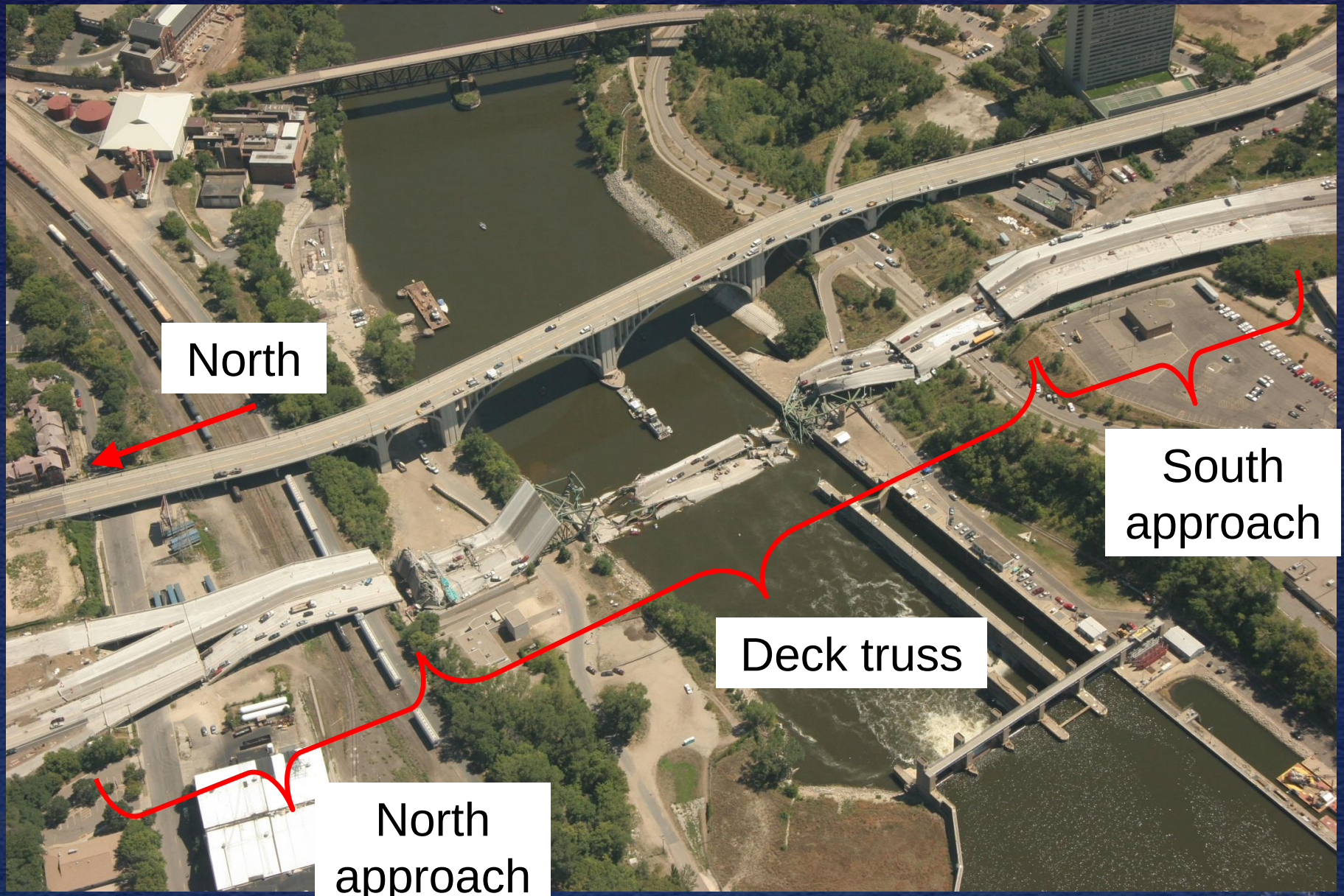
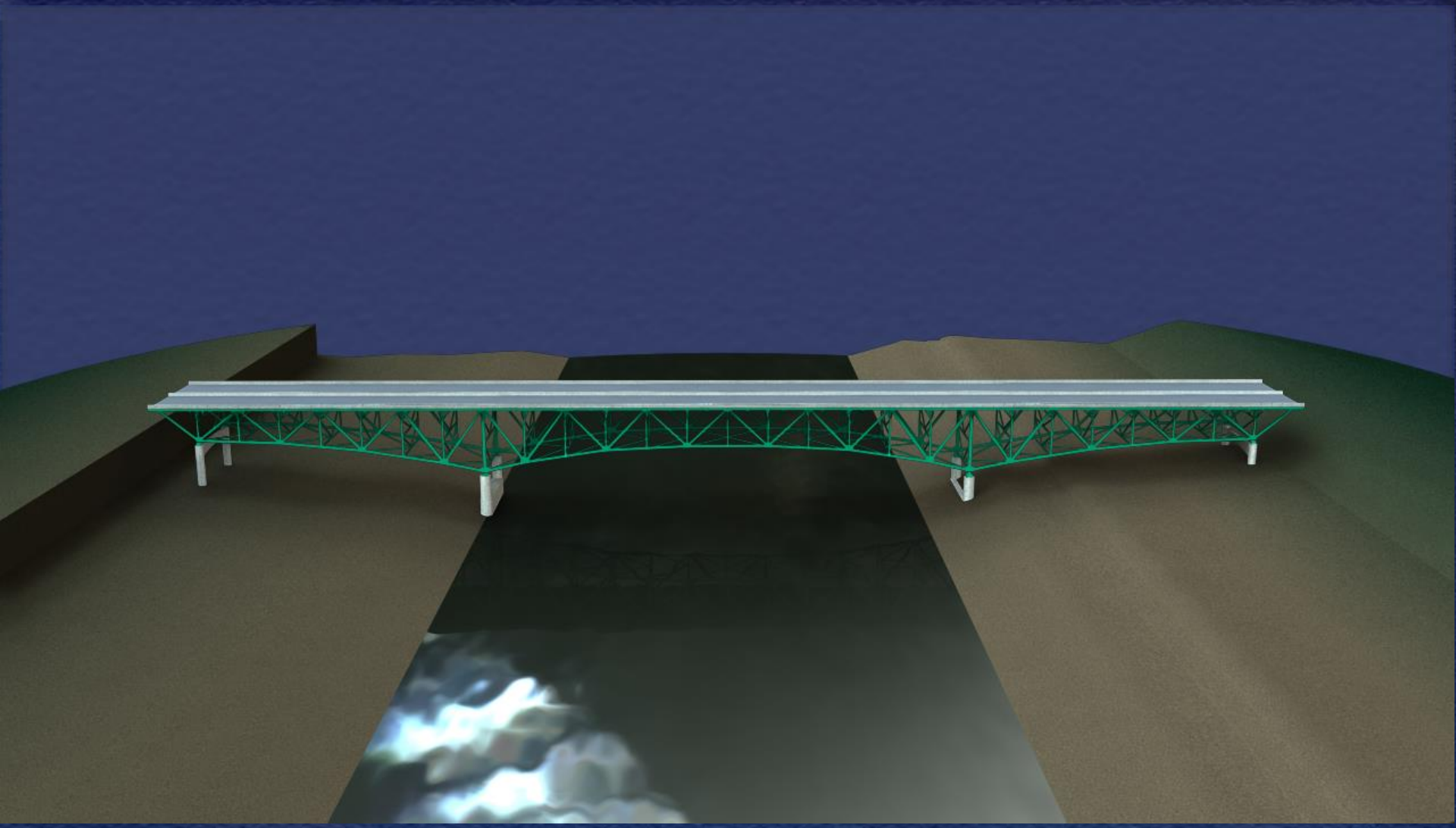

North
South approach
Deck truss
North approach

General Description of the Bridge



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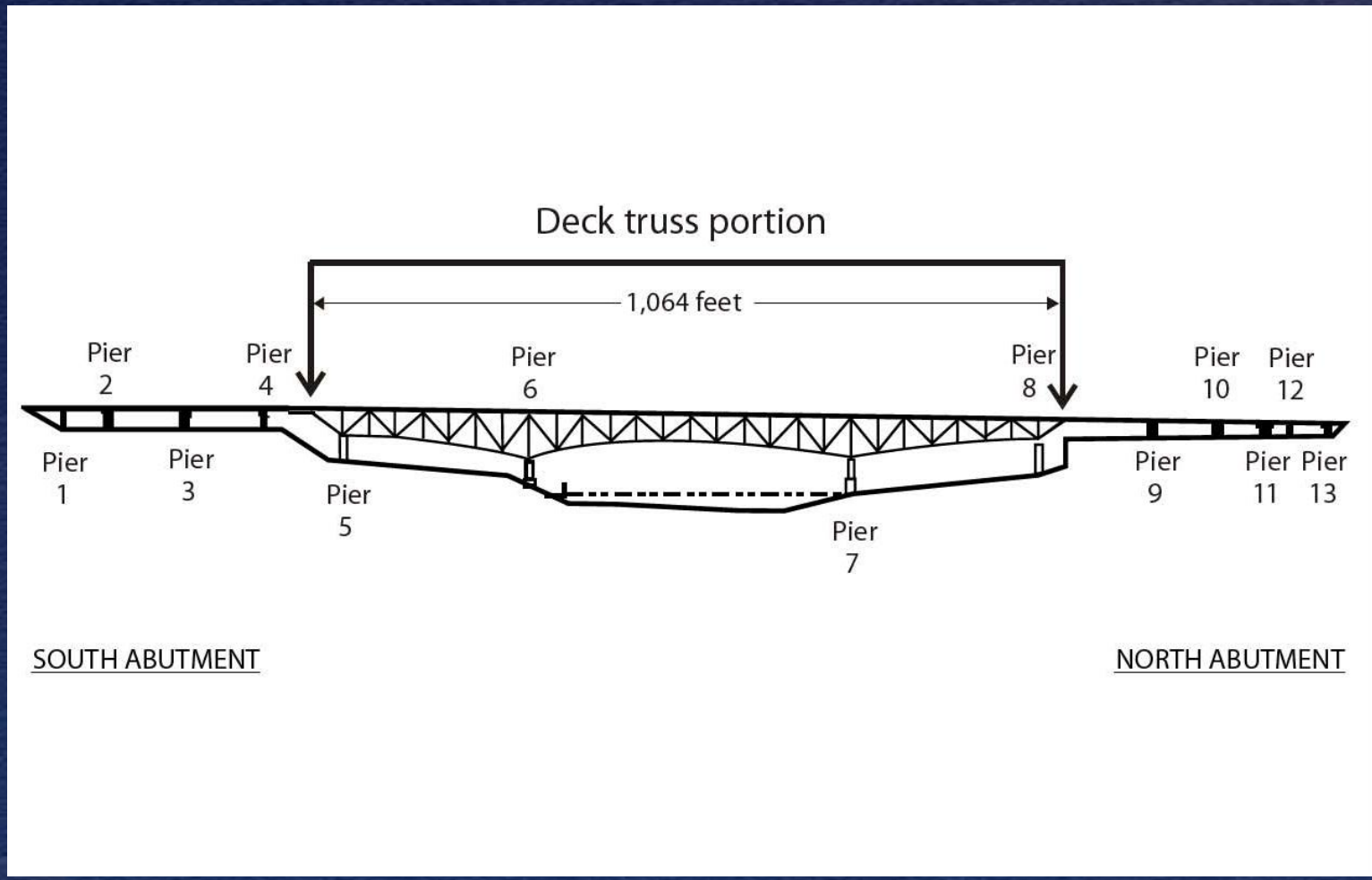


Probable Cause of Failure

The inadequate load capacity, due to design error of the gusset plates at the “U10” connection points by the engineering consulting firm responsible for the bridge design, which failed under a combination of:

1) Substantial increases in the weight of the bridge, resulting from previous bridge modifications; and

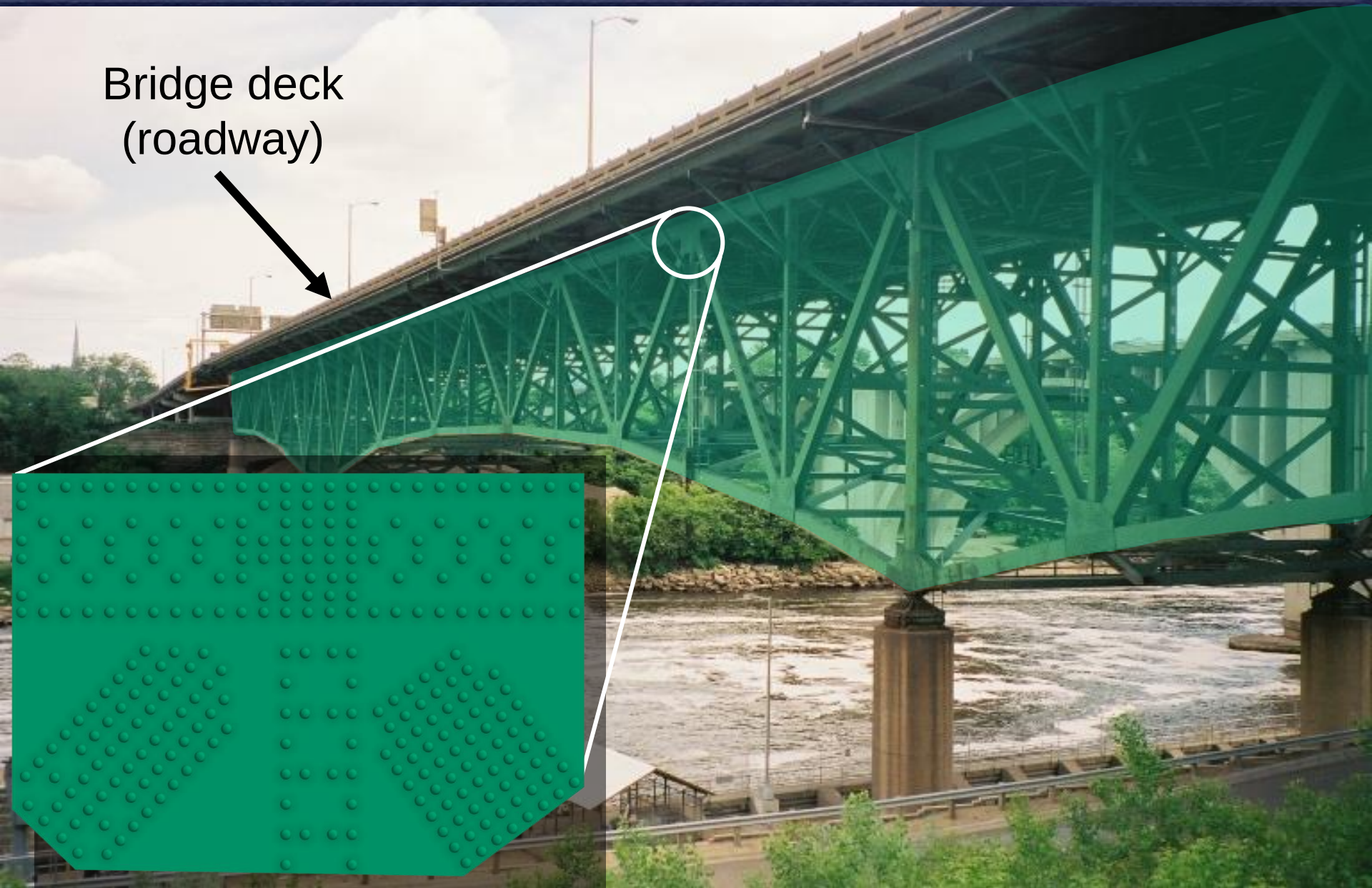
2) Traffic and concentrated construction loads on the bridge the day of the collapse.

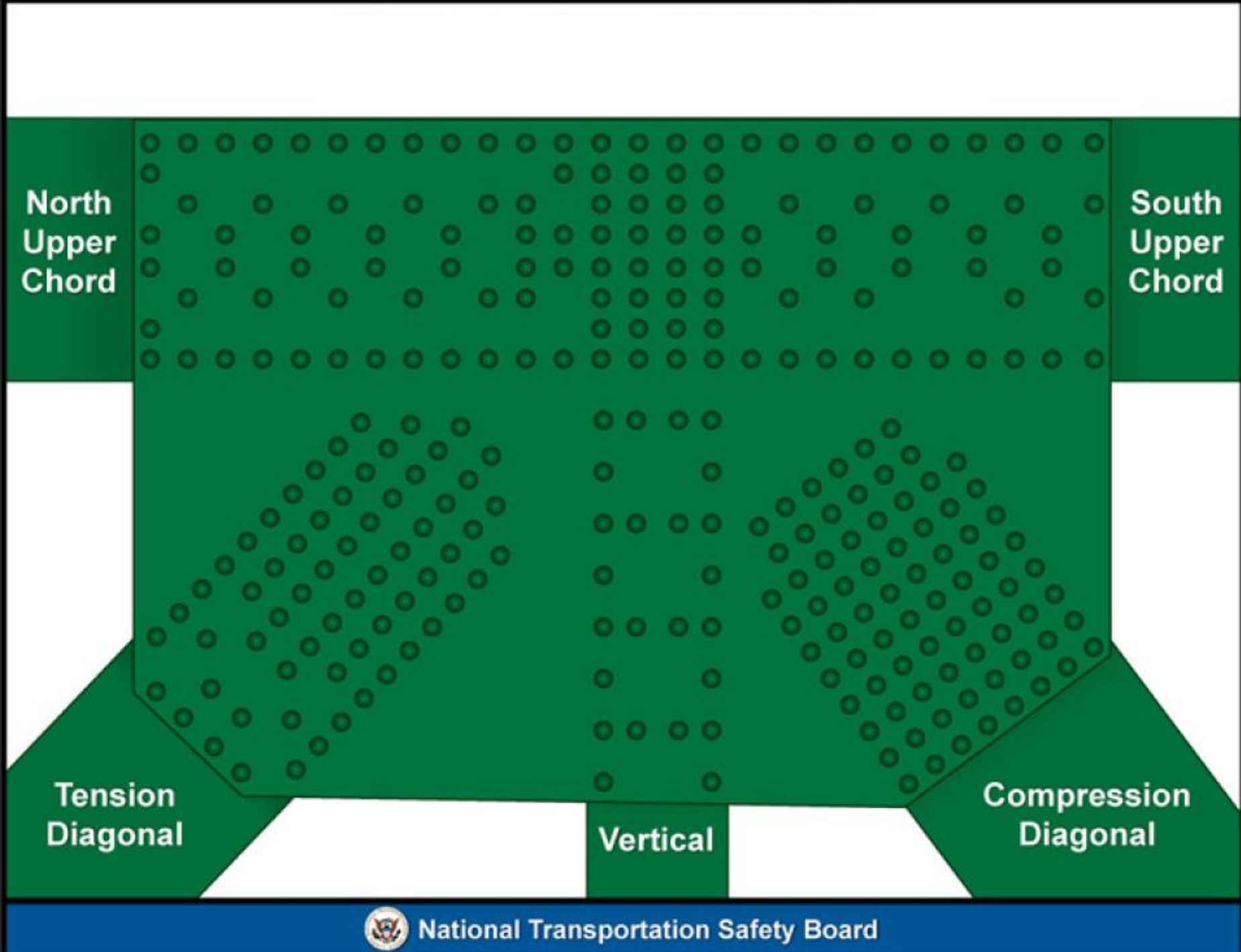
Contributing Probable Cause of Failure

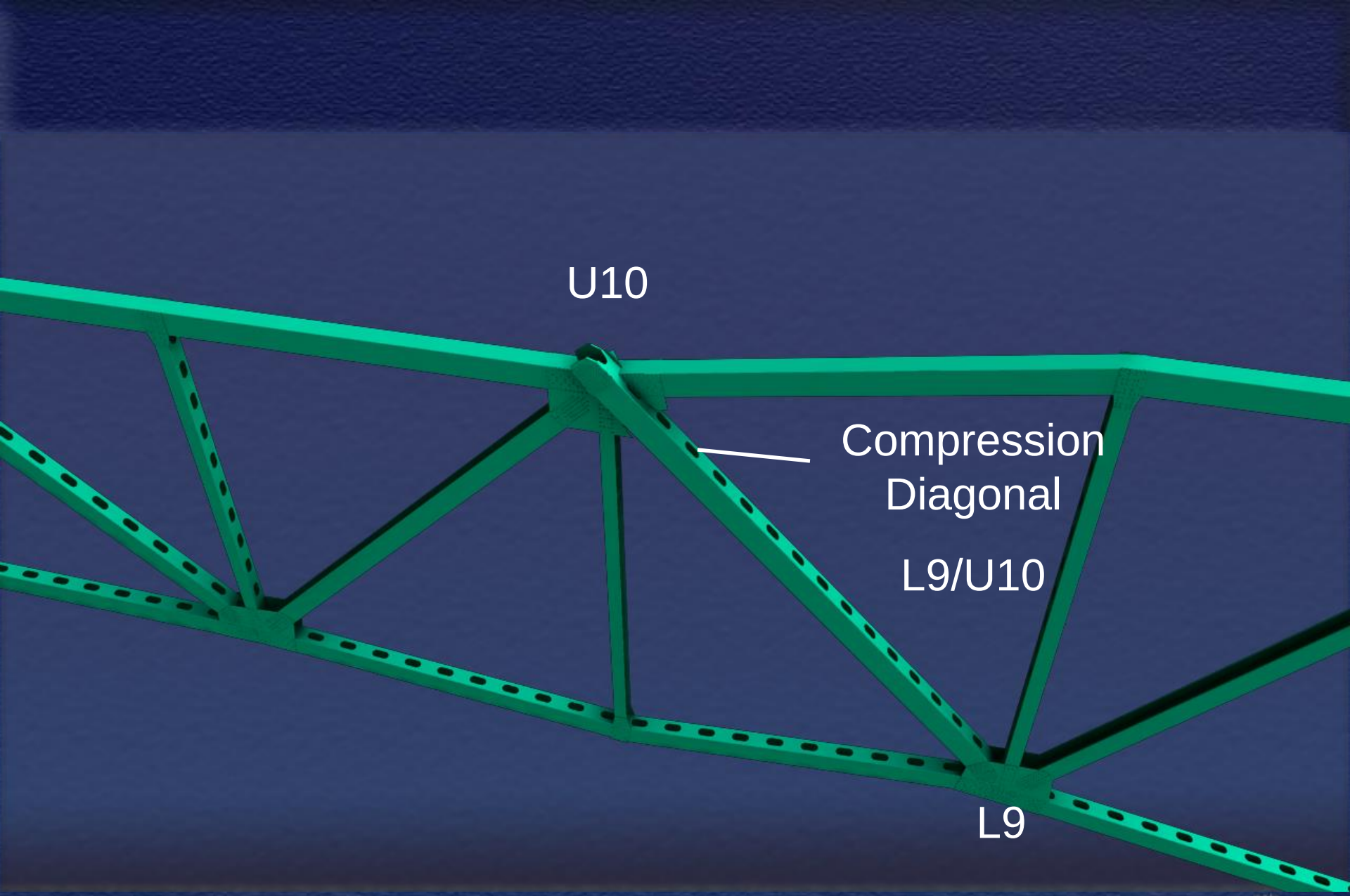
Contributing to the design error was the failure of the engineering consulting firm's quality control procedures to ensure appropriate main truss gusset plate calculations were performed; and the inadequate design review by Federal and State transportation officials.

Contributing to the accident was the accepted practice by these officials of giving inadequate attention to gusset plates during inspections and excluding them from load rating analyses.

I-35W Bridge Information



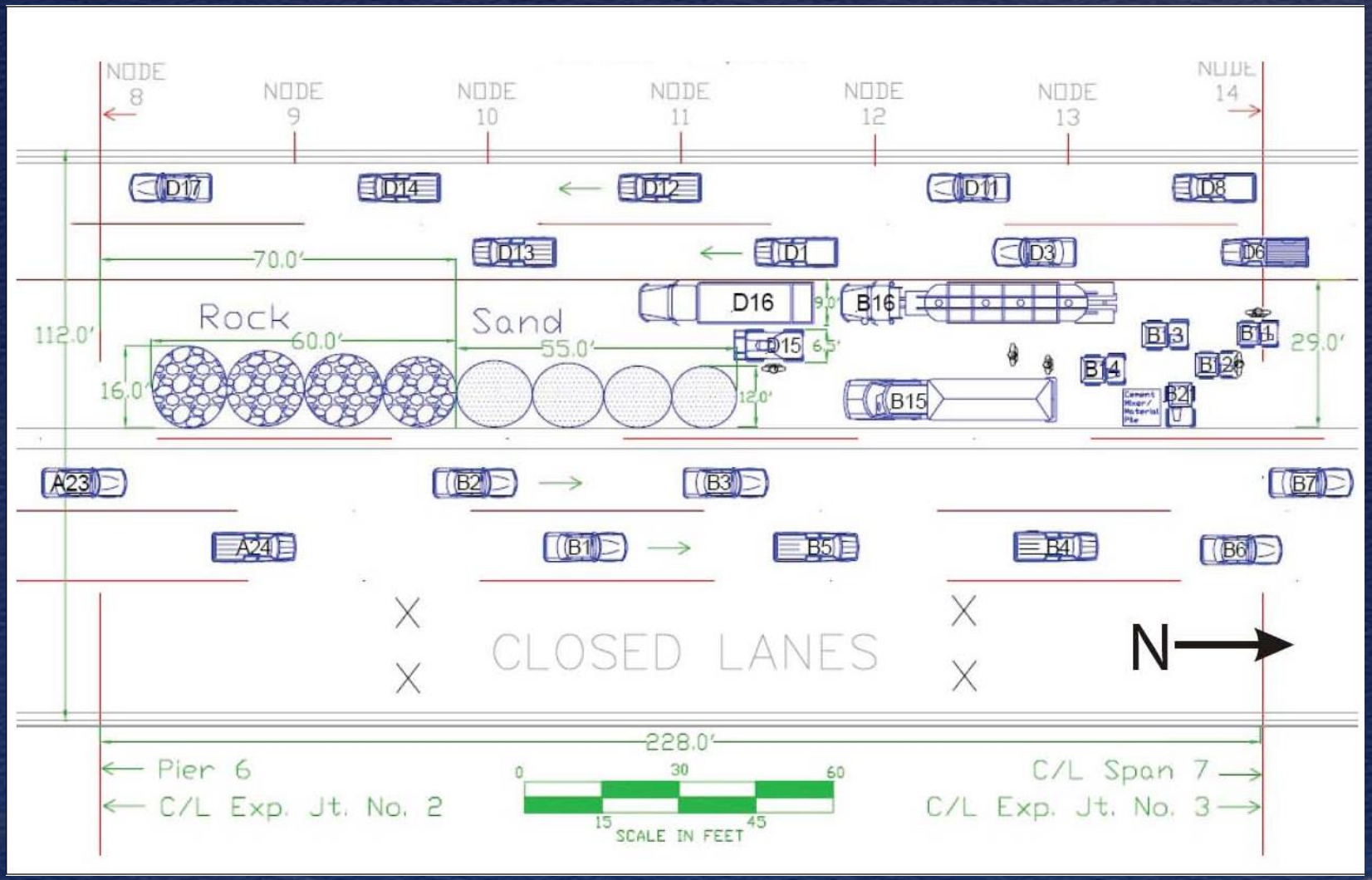

North Upper Chord
South Upper Chord
Tension Diagonal
Vertical
Compression Diagonal
National Transportation Safety Board


U10
Compression
Diagonal
L9/U10
L9

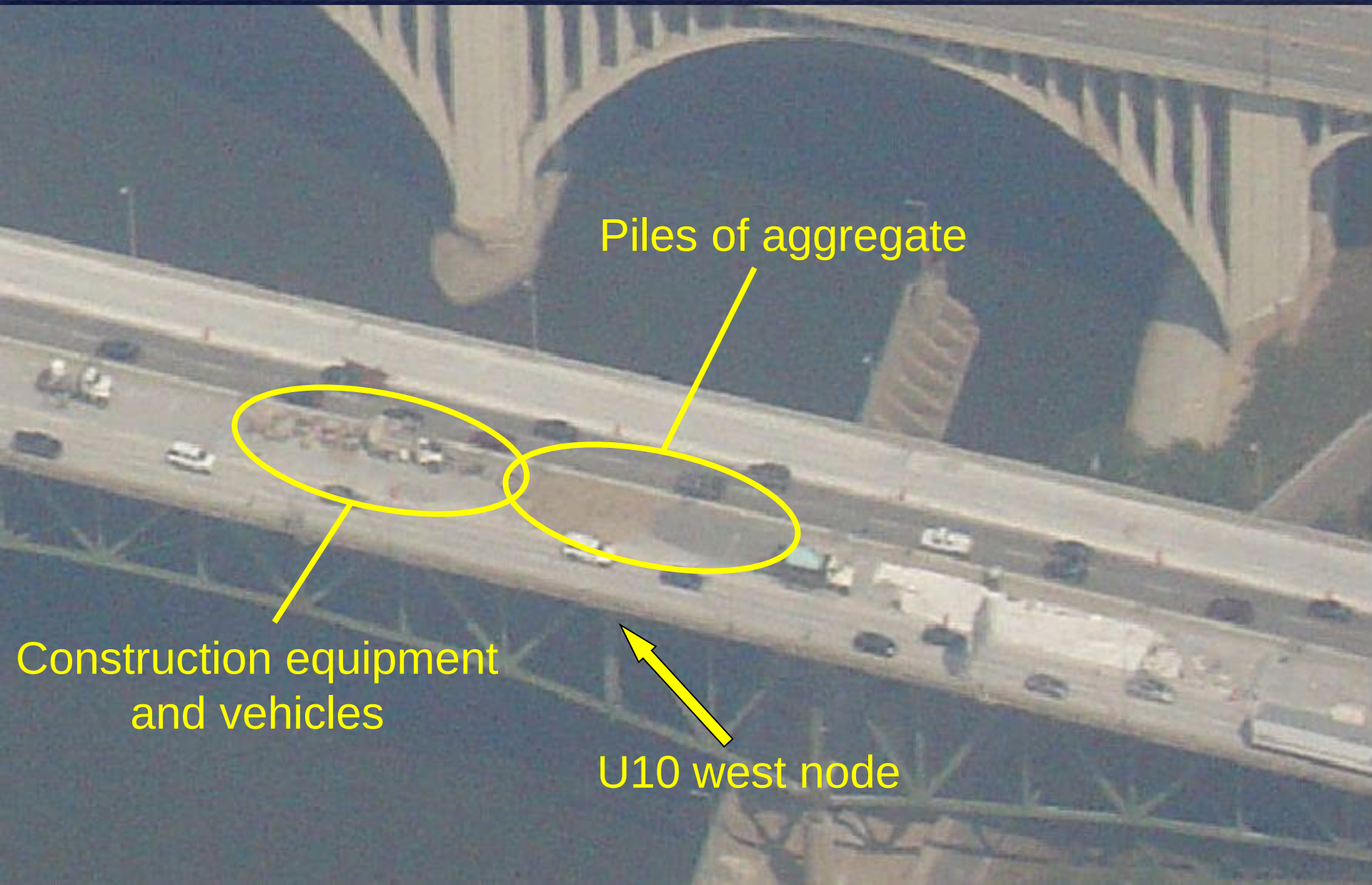
Bridge Modifications

- 1977 – modification to increase bridge deck thickness
  - Bridge dead load increase of 13.4%
- 1998 – modifications to the median barrier and outside railings
  - Bridge dead load increase of 6.1%

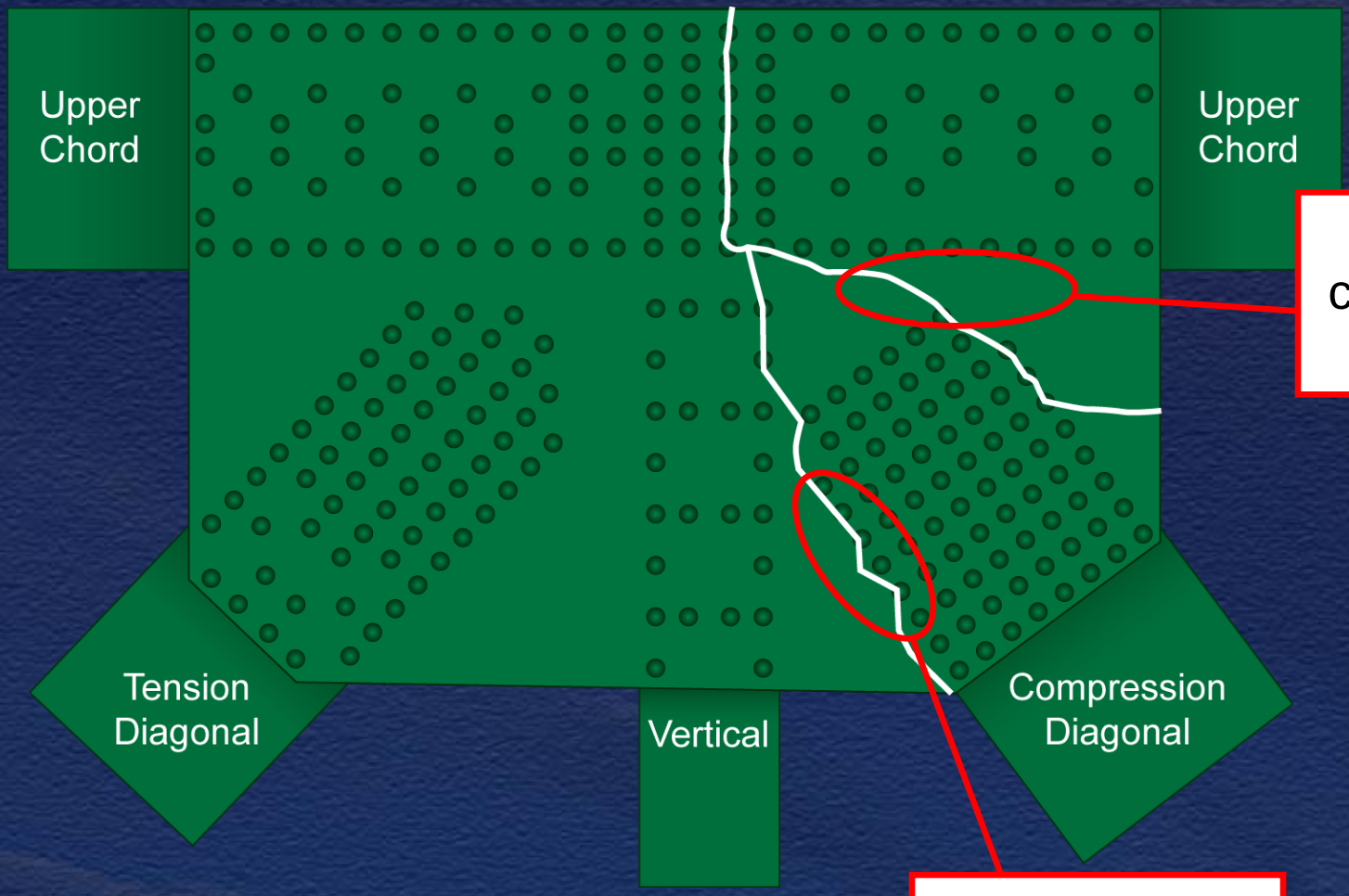
Placement of Additional Loads



Construction Work – Day of Accident



Drawing of Fractures in Node U10E West Gusset Plate



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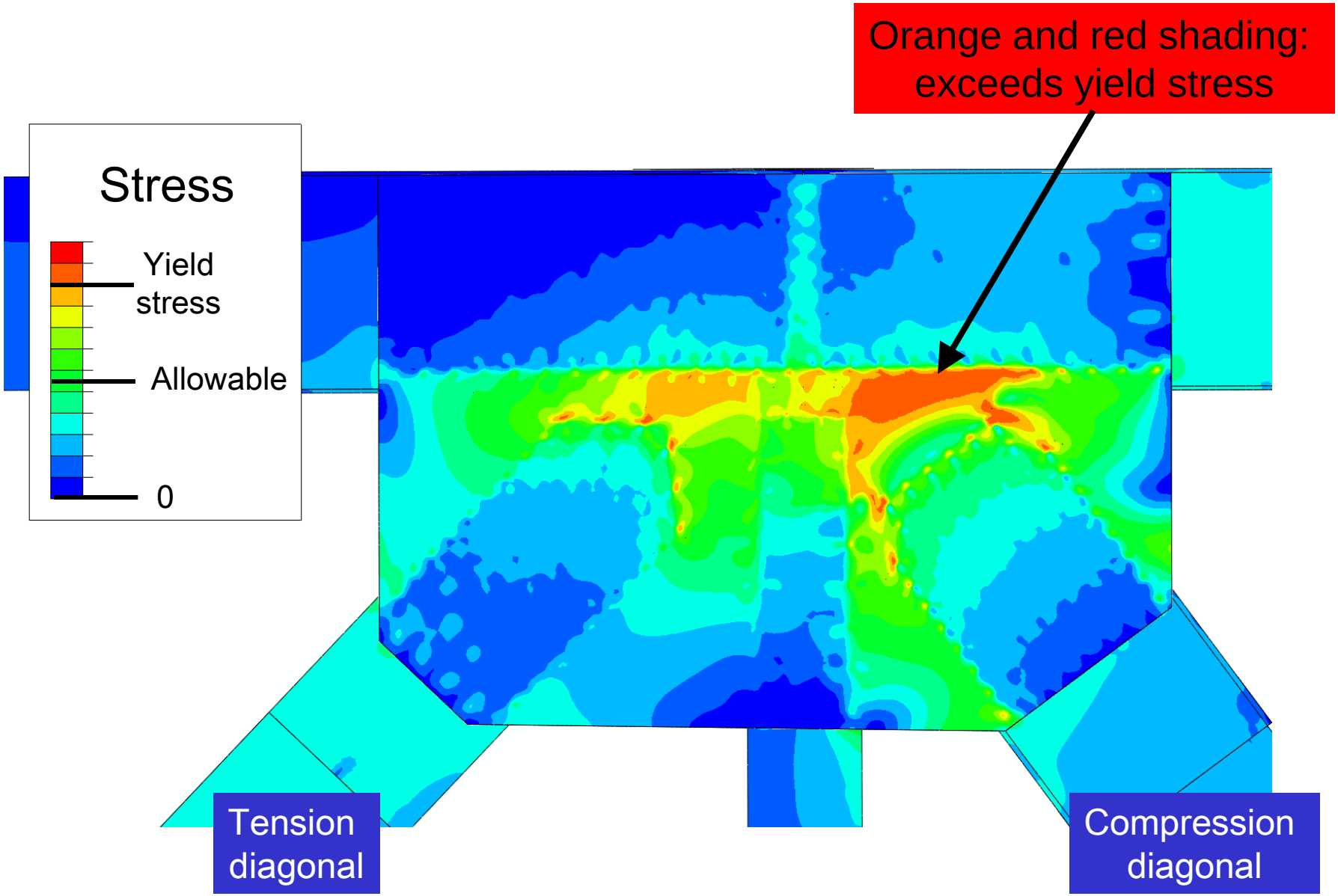
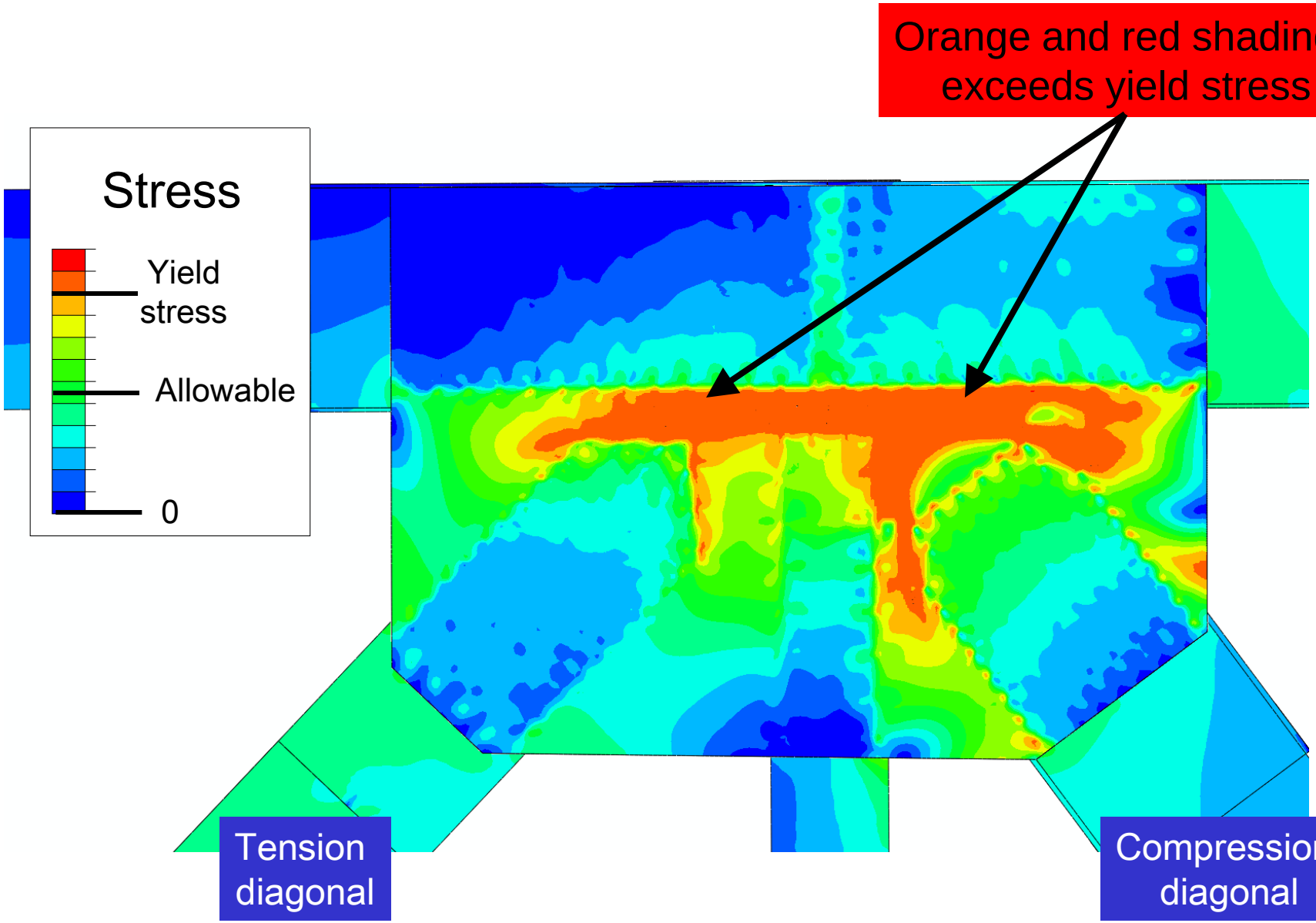
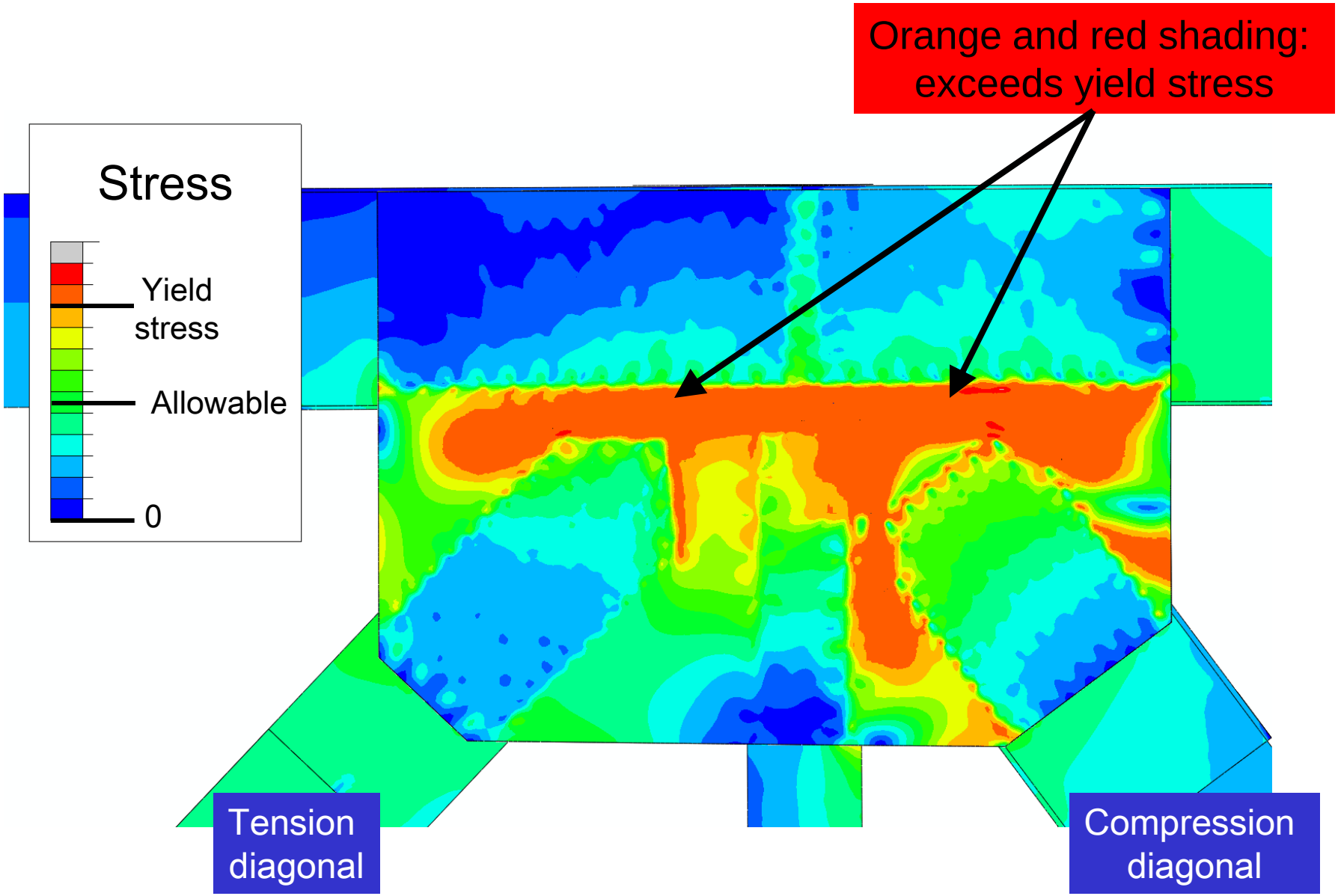
Dead Load of Original 1967 Bridge



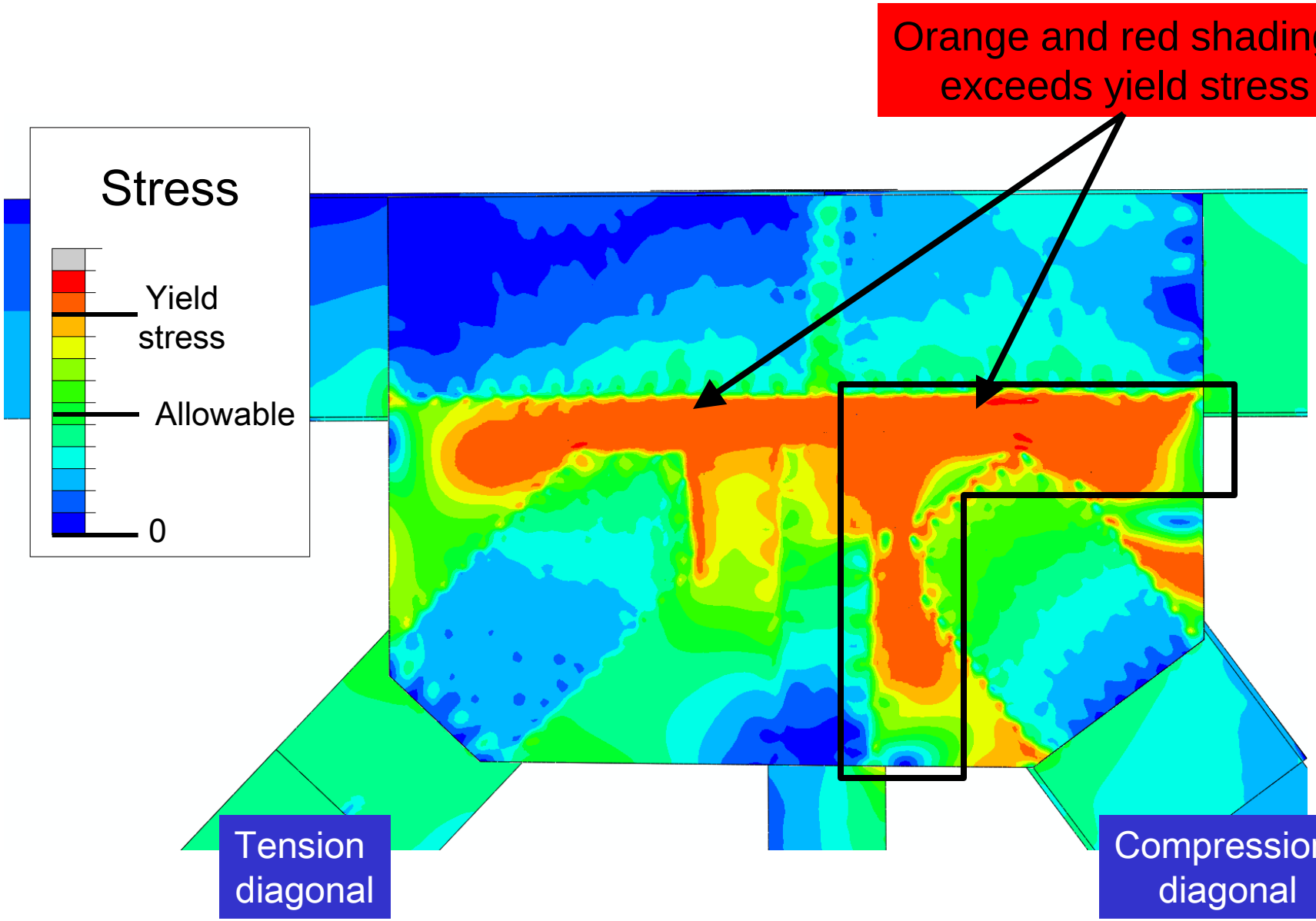
After 1977 and 1998 Modifications

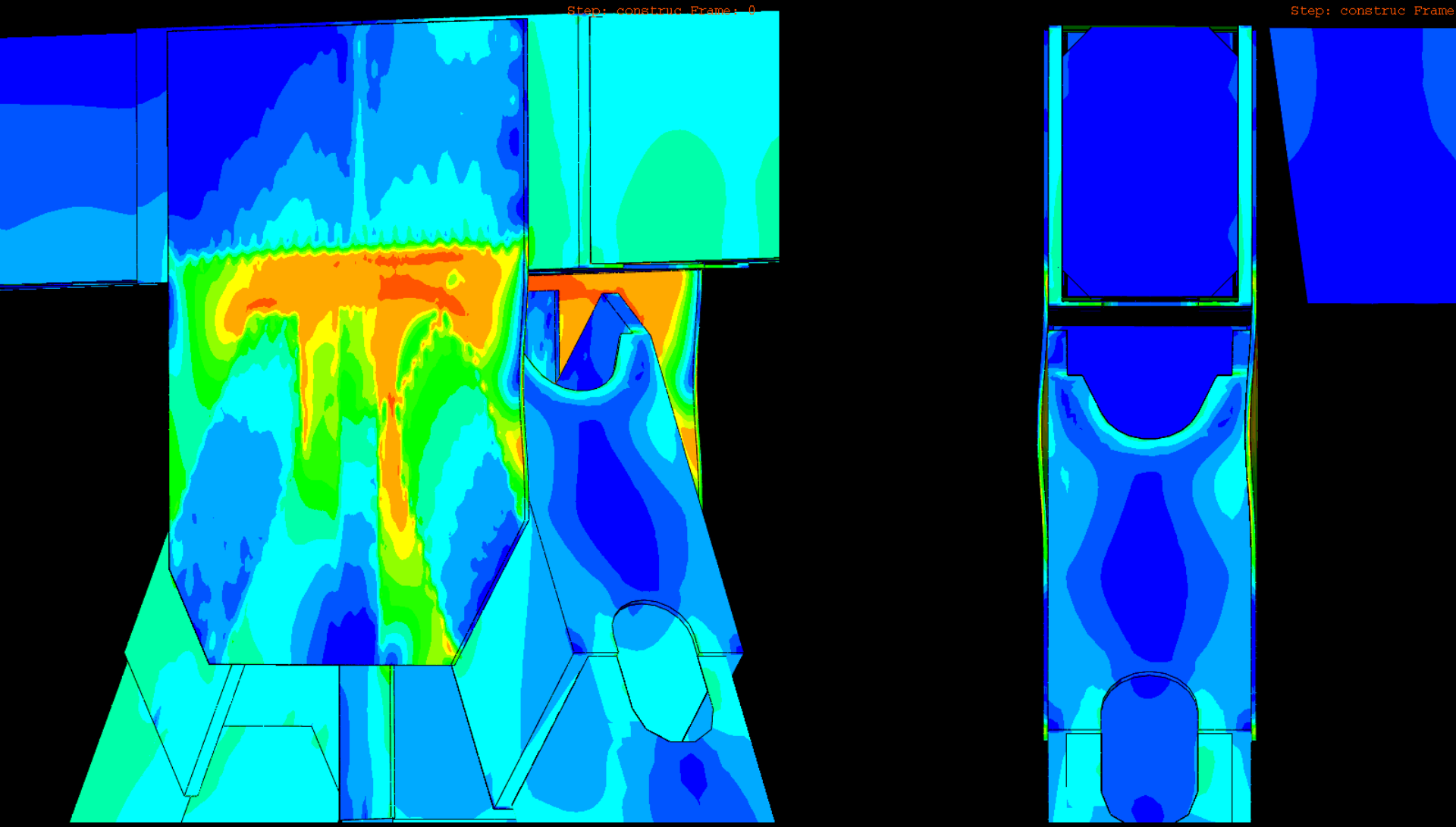


Loads at Time of Accident

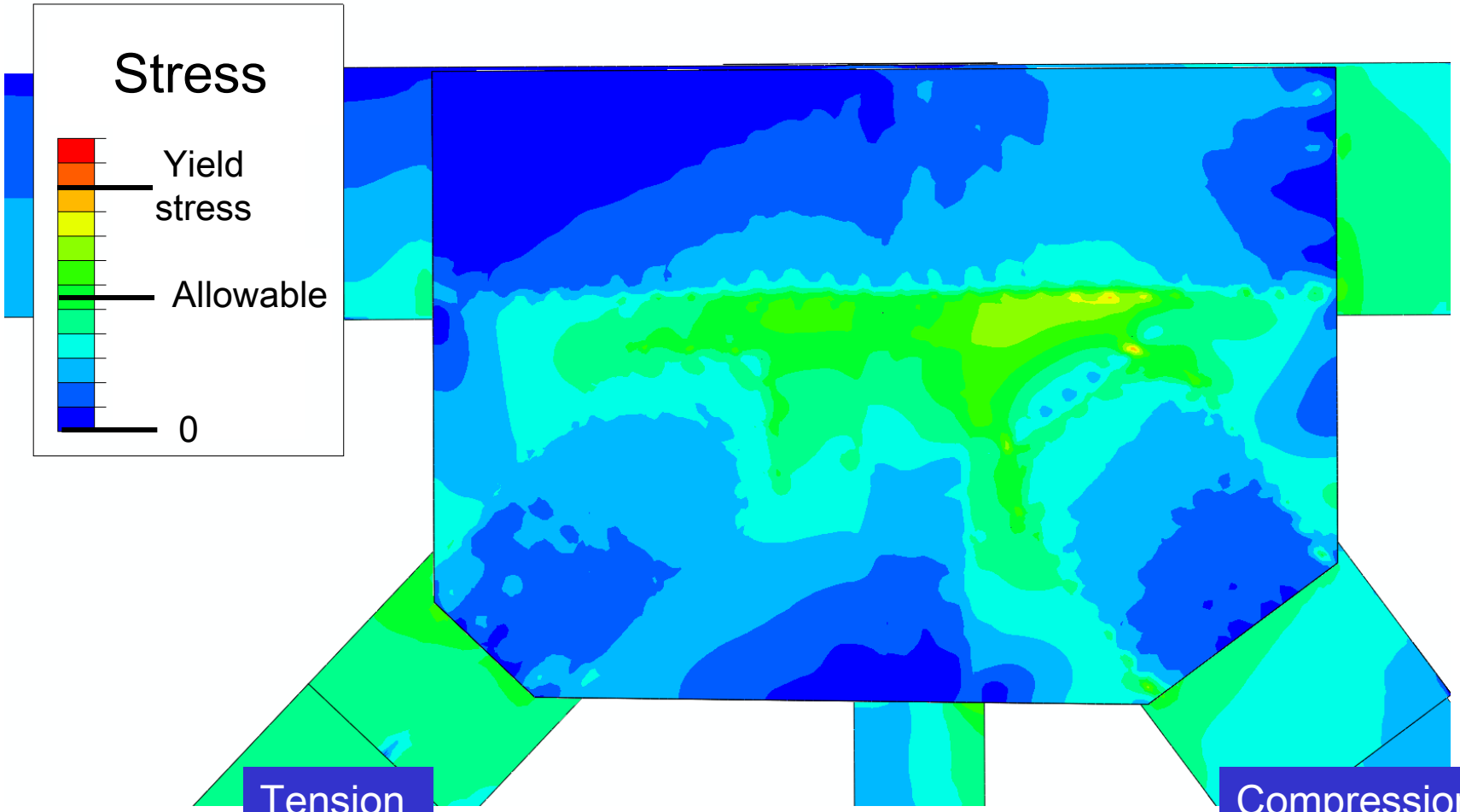


Loads at Time of Accident

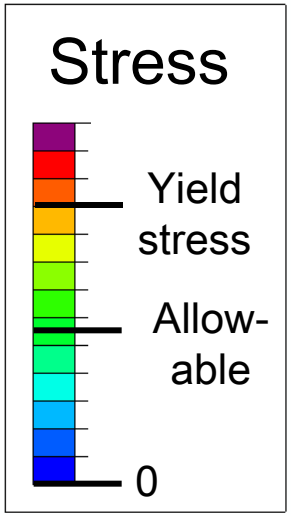



Step: construc Frame: 0
Step: construc Frame

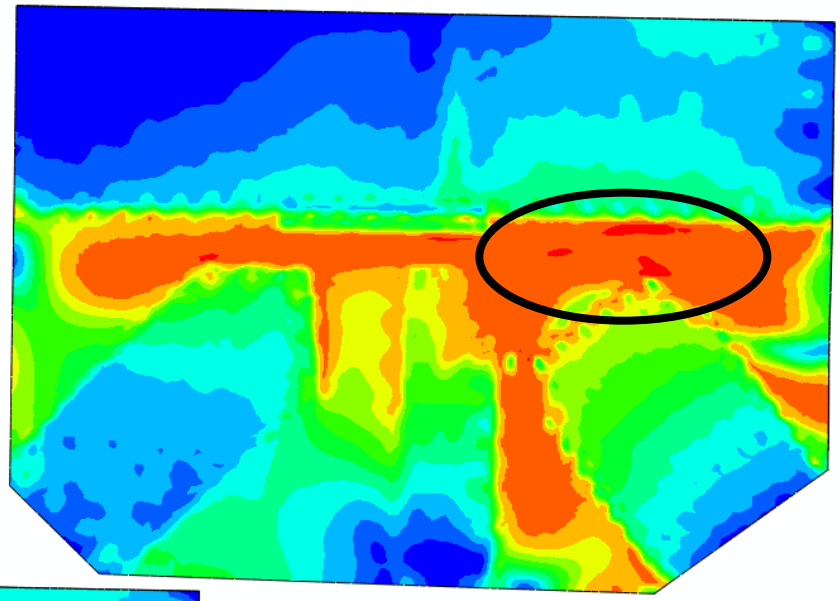
Accident Loads on 1-Inch-Thick Gusset Plates

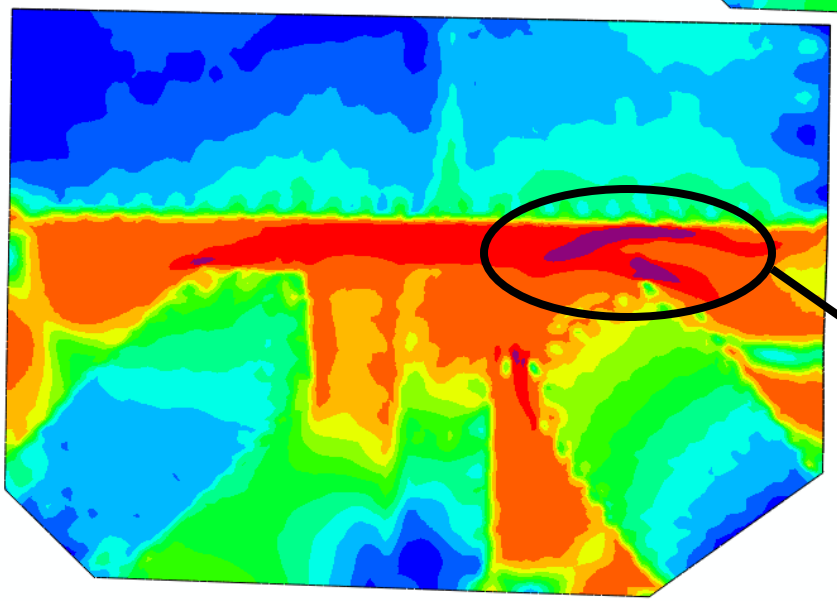


U10 West and U10 East



U10 East



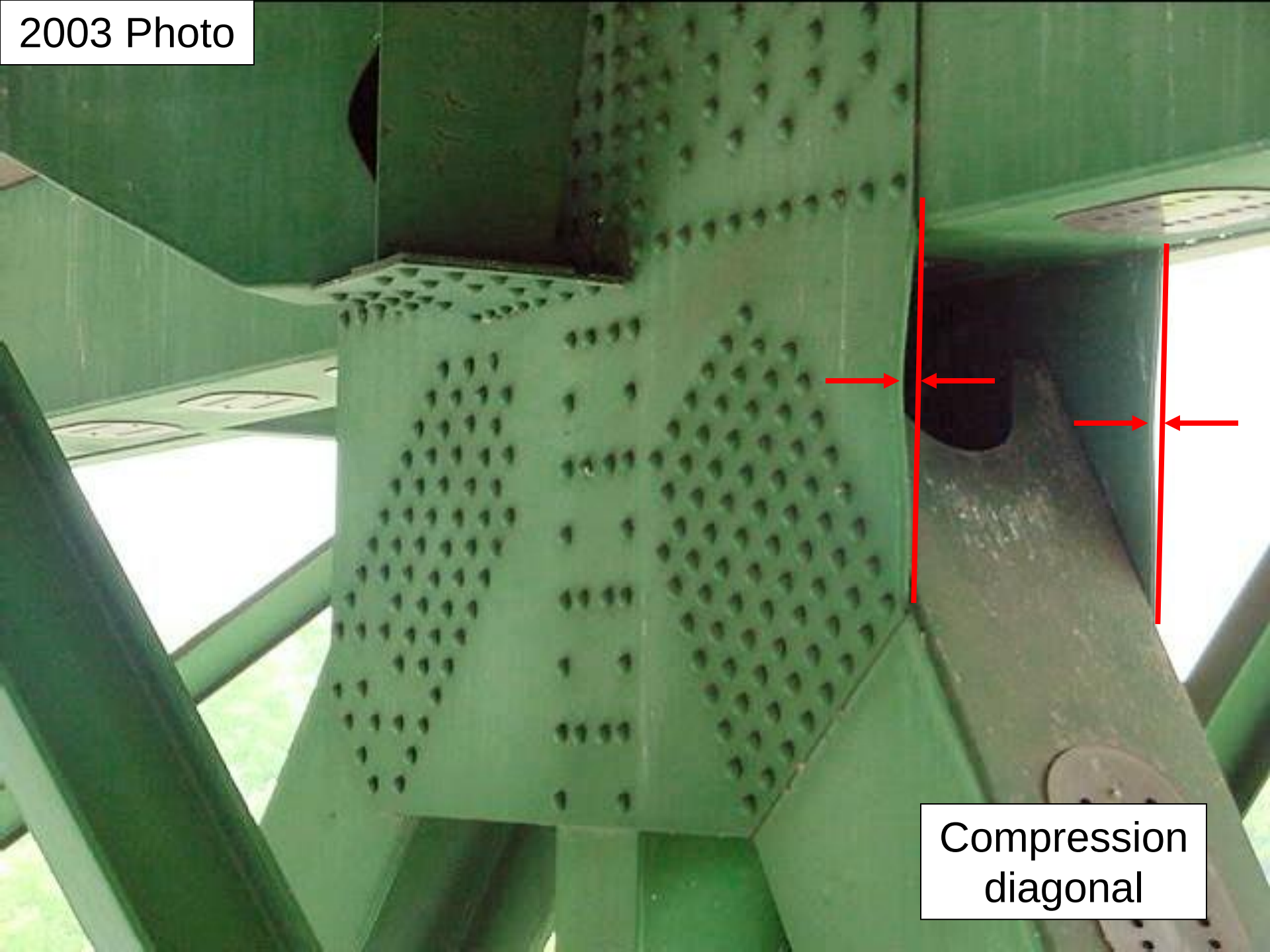


U10 West

Has higher stress at the time of the accident

Standards, Regulations and Guidance

- Federal Highway Administration
  - Inspection requirements (regulations)
  - Construction loading (technical advisories)
- AASHO/AASHTO
  - Initial bridge design
  - Inspections
  - Bridge condition evaluations/load evaluations
- MN/DOT
  - Initial bridge design
  - Construction projects


2003 Photo
Compression diagonal

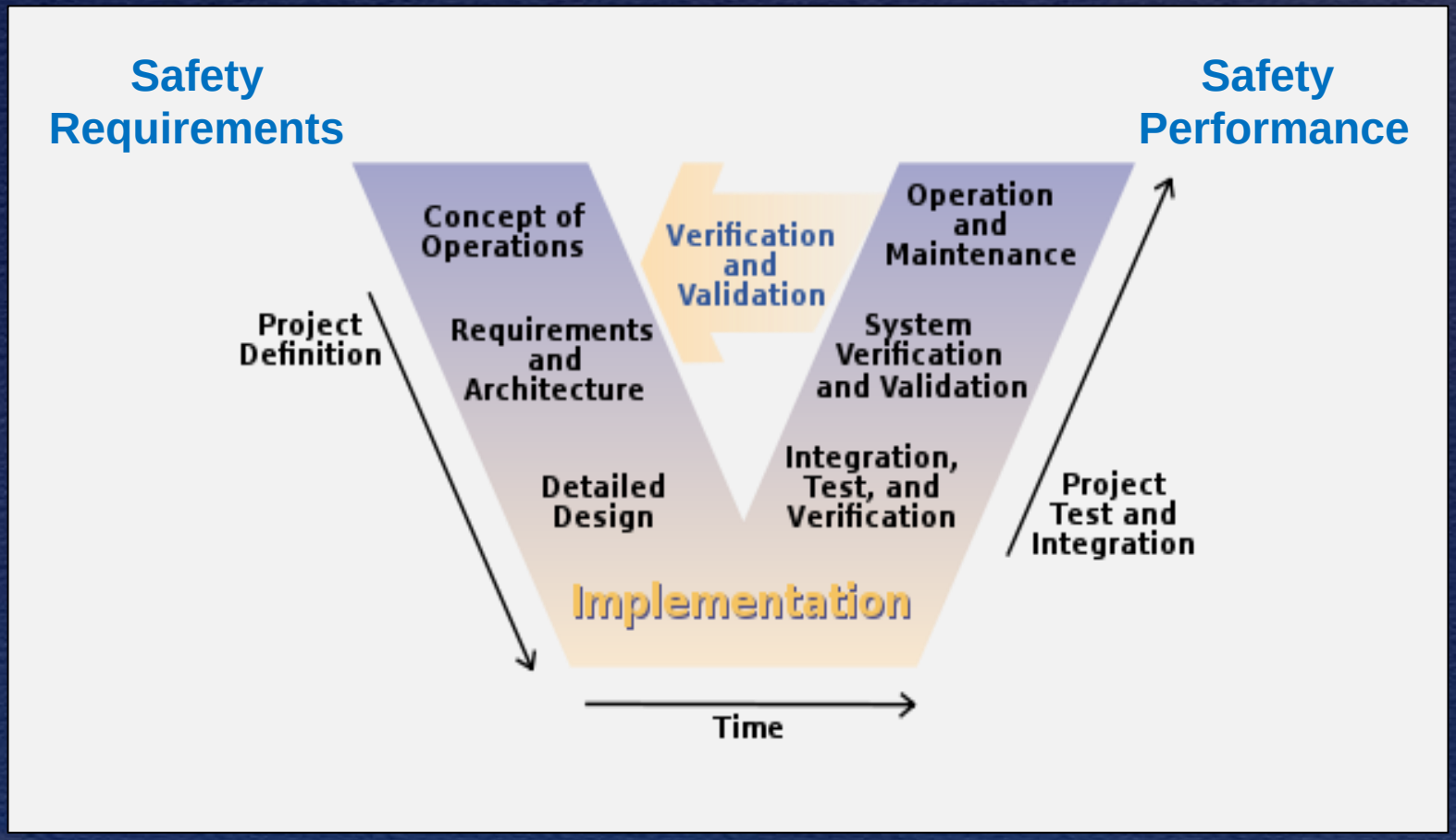
Missed Opportunities

- Design, construction, and inspection guidance materials focused on members and other structural elements only.
- Bridge safety inspection engineer – noticed, but made poor assumptions and did not document.
- Evaluations by URS/U. of Minnesota, failed to identify bowing condition, although captured photographic evidence.
- Decision to allow staging of aggregates on bridge deck truss.

Follow-on

- Investigation revealed a number of other instances where questionable bridge designs have been certified and approved for construction.
  - 10 States acknowledged approving designs later found deficient
  - At the time, 2008, all but one of these approvals had occurred in the previous 10 years (most within the previous 6 years)

Generalized System Engineering V



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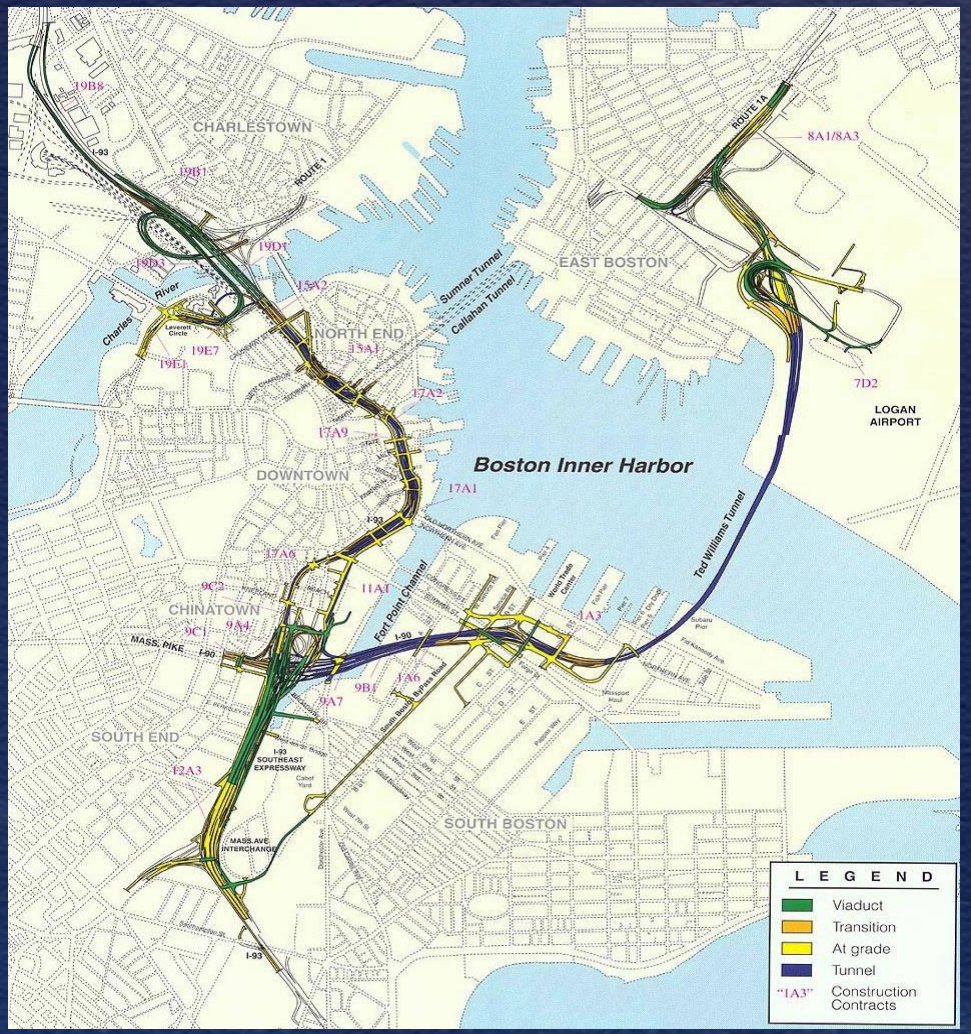
Ceiling Collapse in I-90 Connector Tunnel Boston, MA



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Ted Williams Tunnel
D Street Portal
I-90 Connector Tunnel
NORTH
LEGEND
Viaduct
Transition
At grade
Tunnel
Boston Inner Harbor
CHARLESTOWN
EAST BOSTON
NORTH END
DOWNTOWN
CHINATOWN
SOUTH END
SOUTH BOSTON
LOGAN AIRPORT
Sumner Tunnel
Callahan Tunnel
Fort Point Channel
Ted Williams Tunnel
MASS. PIKE
I-90
I-93
ROUTE 1
ROUTE 1A
I-93 SOUTHEAST EXPRESSWAY
MASS.AVE INTERCHANGE
Charles River
Leverett Circle
19B8
19B1
19D1
19D3
19E7
19E1
15A2
15A1
17A2
17A9
17A1
17A6
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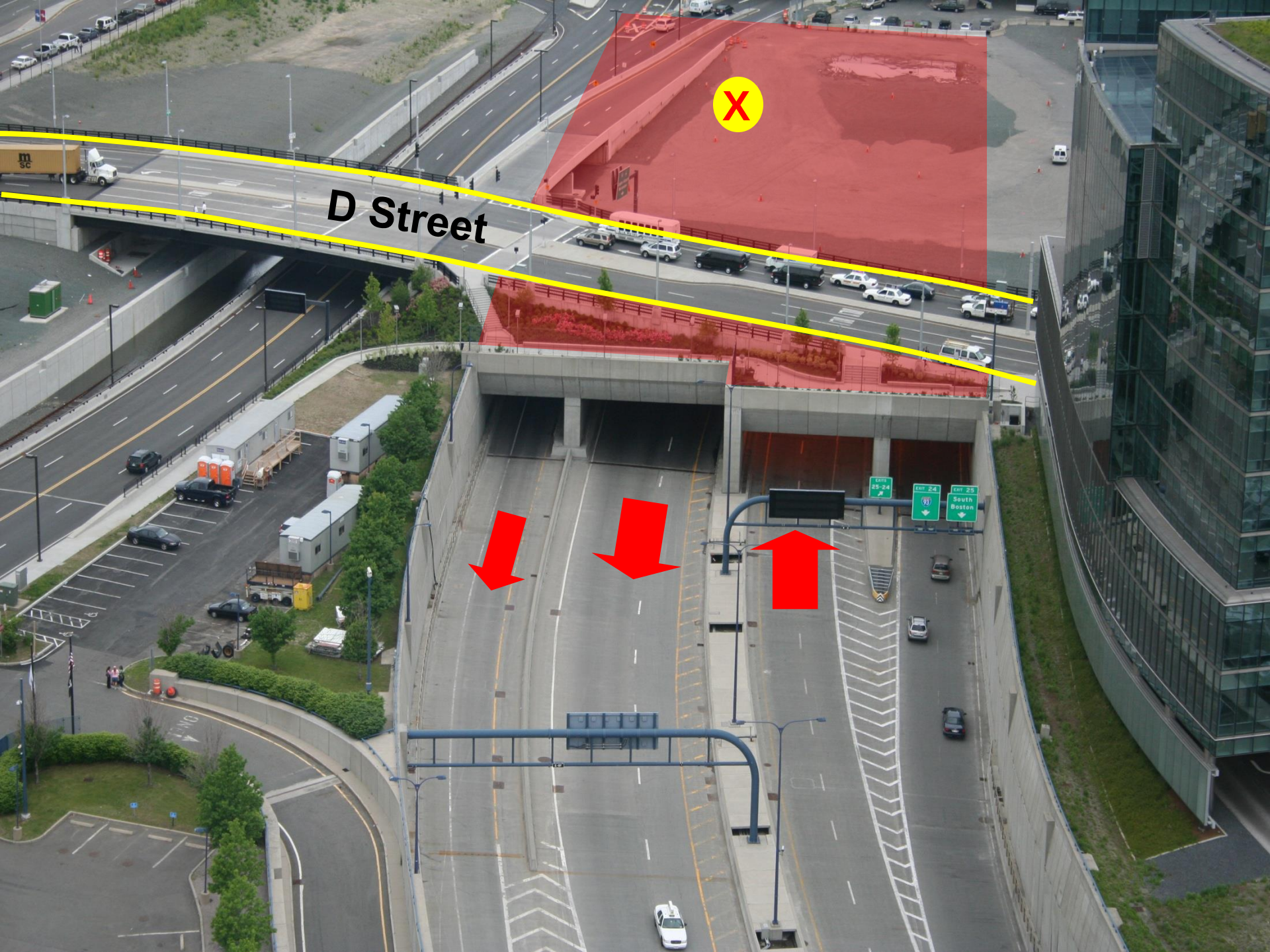
9C2
9C1
9A4
9A7
9B1
12A3
8A1/8A3
7D2
1A3


X
D Street
msc
EXIT 25-24
EXIT 24
93
EXIT 25
South Boston

Source: Mass. State Police

Source: Mass. State Police

Source: Mass. State Police

Probable Cause of Failure

The use of an epoxy anchor adhesive with poor creep that could not sustain long-term loads.

The failure of the project consultants to identify creep as a critical long-term issue, and account for it in the design, specifications, and approval process for an anchoring system.

The failure of the epoxy provider to provide the consultants sufficient information to determine the suitability of the product to sustain long-term tensile loads.

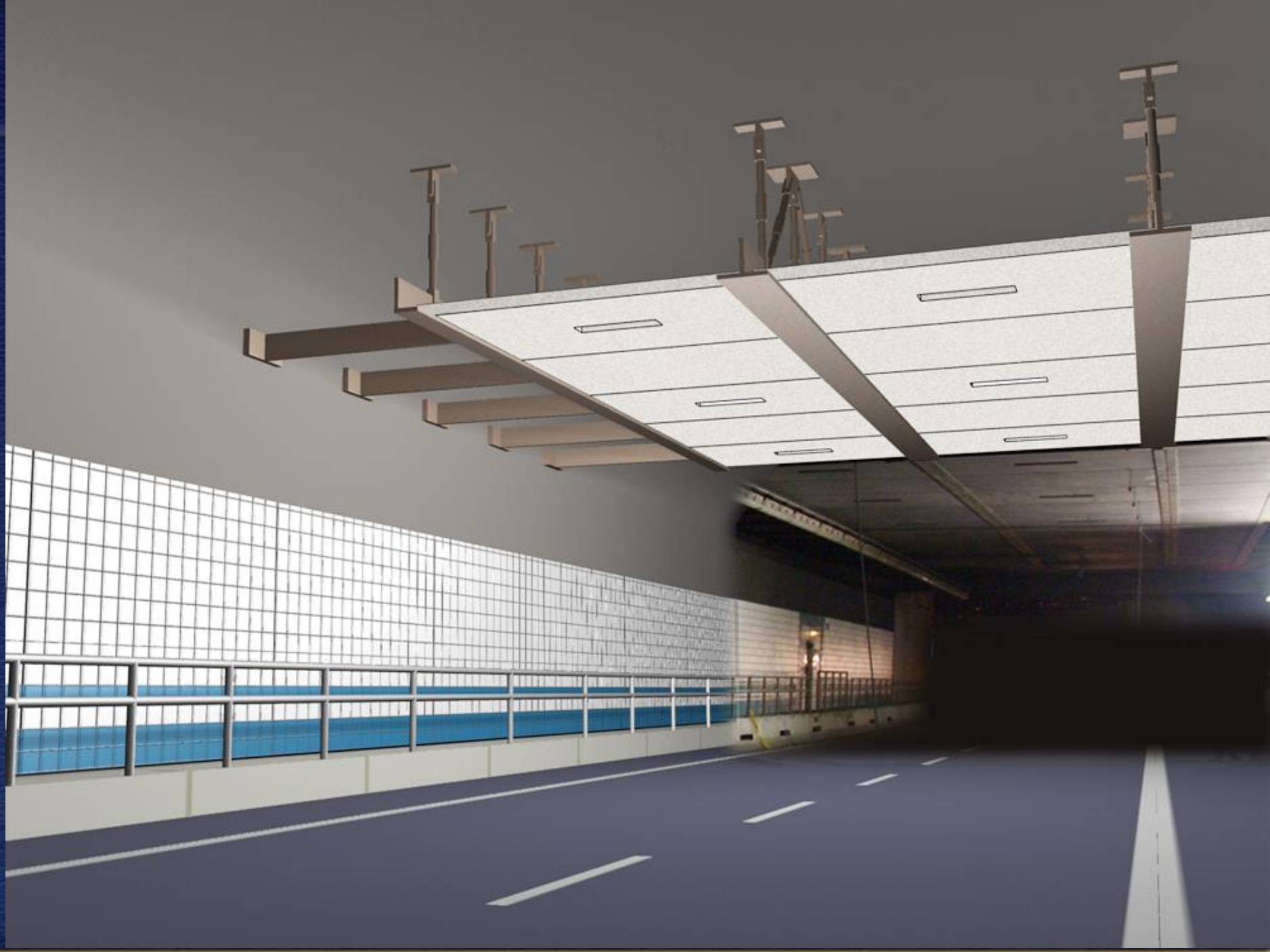
Probable Cause of Failure

Contributing to the accident:

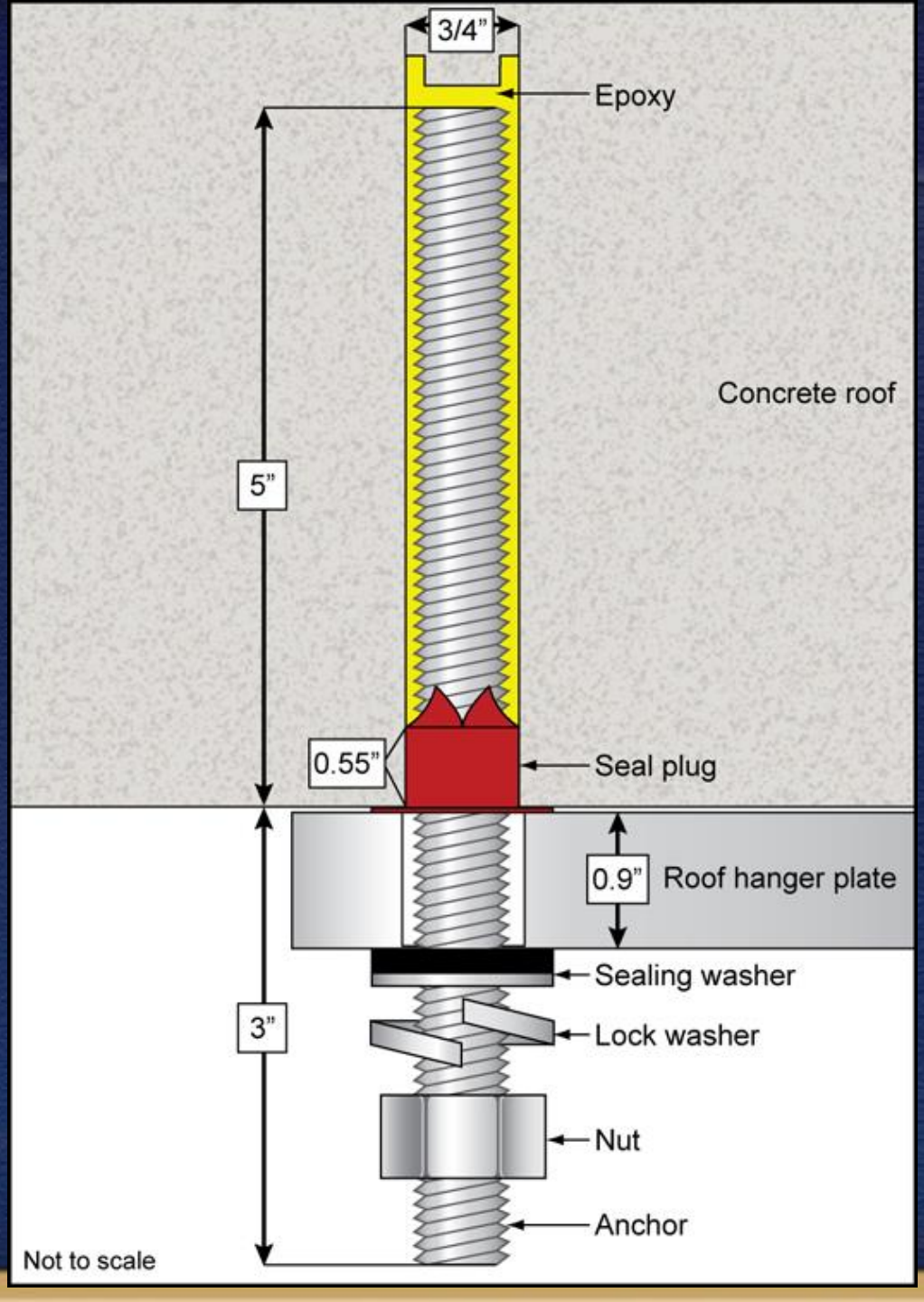
- Failure of the epoxy provider to identify the unsuitability of the epoxy in a previous anchor application.

- Failure of project contractors to continue to monitor the anchors, after the first instance of anchor displacement.

- Failure of the Turnpike authority to implement an inspection program.



Displaced Anchors


3/4"
Epoxy
Concrete roof
5"
0.55"
Seal plug
0.9"
Roof hanger plate
Sealing washer
3"
Lock washer
Nut
Anchor
Not to scale

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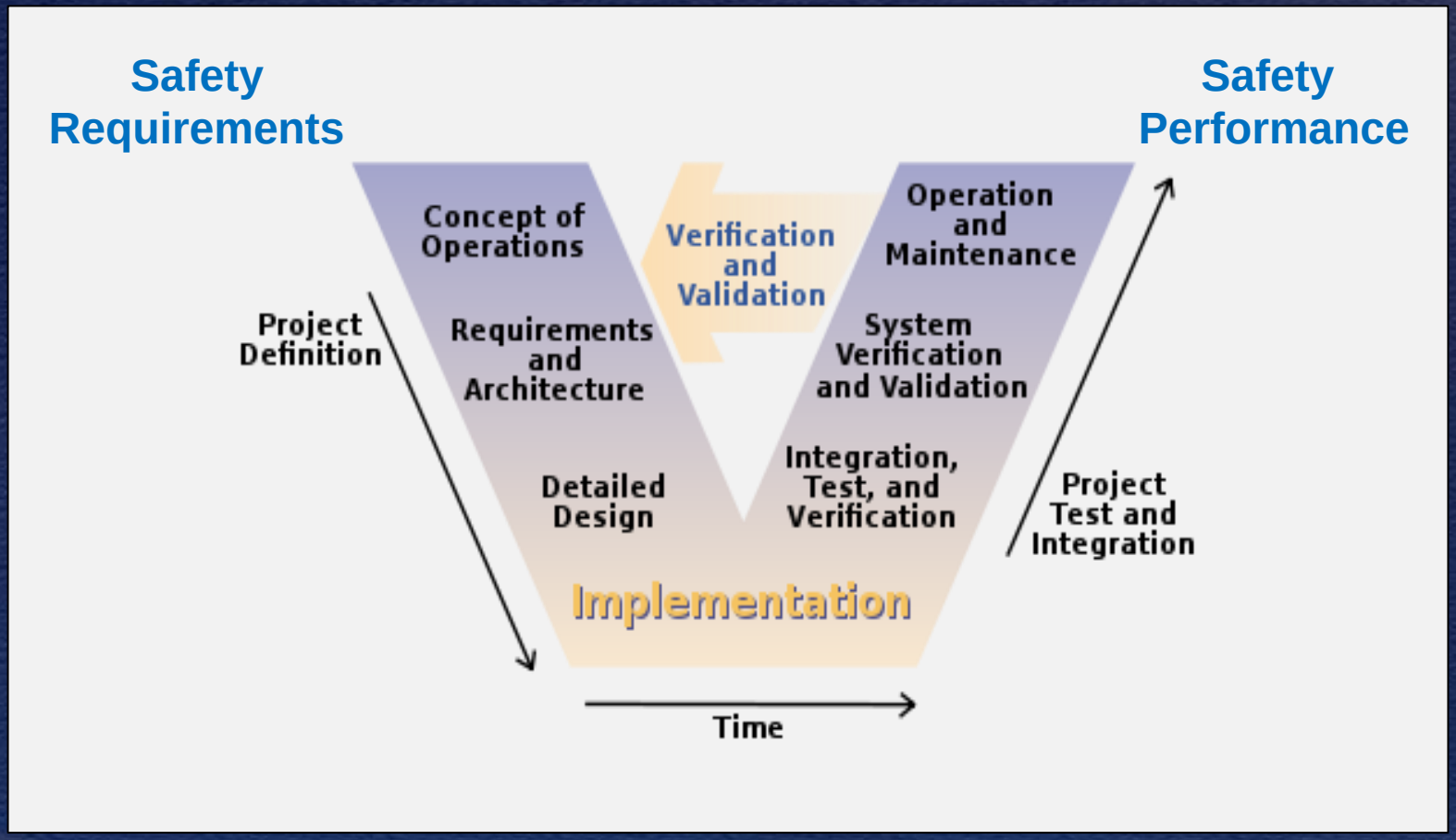
Missed Opportunities

- Construction project consultant's limitations on choice of anchoring system
- Lack of clarity on types of epoxy available/provided
- Insufficient approval review by design consultant – which failed to identify the type of epoxy and note the limits on its use.
- After initially discovering the displacement of anchors, failing to identify the cause.
- After taking some action, failing to follow up to ensure action was appropriate and issue resolved.

Question Assumptions

- Reliance on standards and testing that did not properly assess or account for key characteristics of critical infrastructure components
- Reliance on false assumptions, rather than focusing on actual, visual evidence.
- ***When the performance requirements change, the front-end V requirements need reassessment***

Generalized System Engineering V



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